SYSTEMATIC REVIEW

Revision in Ceramic-on-Ceramic and Ceramic-on-Polyethylene Bearing in Primary Total Hip Arthroplasty with Press-fit Cups: A Systematic Review and Meta-analysis of Different Methodological Study Designs

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Abstract

Background: The influence of bearing on revision, especially in press-fit modular cup total hip arthroplasty (THA), remains underexposed.

Methods: A systematic literature review was conducted in PubMed, Embase, Cochrane Library, and ClinicalTrials.gov in line with the PRISMA guidelines. The primary outcome was overall revision between ceramic-on-ceramic (CoC) and all sorts of ceramic-on-polyethylene (CoPE) bearings. As secondary outcomes complications and reasons for revision were compared between bearings. Outcomes were presented in subgroups based on study design (randomized controlled trials (RCT), non-randomized comparative, and registry studies). The quality of evidence was assessed using the GRADE. The risk of bias was assessed using the Cochrane collaboration's tool and the MINORS criteria.

Results: This meta-analysis included twelve RCTs, three non-randomized comparative studies and two registry studies, including 38,772 THAs (10,909 CoPE and 27,863 CoC). Overall revision showed a lower risk in CoPE compared to CoC in the two registry studies (HR 0.71 (95%CI 0.53; 0.99)) (very low-quality GRADE evidence). In RCTs and non-randomized comparative studies, no difference was observed (low-quality GRADE evidence). Loosening, dislocation, infection, and postoperative periprosthetic fracture showed no significant differences in risk ratio for all designs.

Conclusion: The lower risk of overall revision in registry studies of primary THA with a press-fit modular cup using CoPE bearing compared to CoC should be considered preliminary since this outcome was just slightly significant, based on very low-quality GRADE evidence and based on only two studies with several limitations. Since no difference was observed in the other methodological designs and the separate reasons for revision showed no significant difference in all designs either, no preference for CoC or CoPE can be expressed, and therefore both seem suitable options based on the available literature. More comparative long-term studies are needed to confirm the potential advantages of wear-reduction of both bearings since the currently available literature is limited.

Level of evidence: I

Keywords: Ceramic-on-ceramic, Ceramic-on-polyethylene, Press-fit, Revision, Total hip arthroplasty

Introduction

In total hip arthroplasty (THA) various bearing surfaces have been investigated and developed. A polyethylene (PE) or highly cross-linked PE (HXLPE) inlay in combination with a ceramic head is still considered the option of choice. [1] The main reason for long-term revision is aseptic loosening caused by

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liner wear-induced osteolysis. [2] Hard-on-hard low-friction bearings like ceramic-on-ceramic (CoC) are one of the options to overcome liner wear. In CoC wear rates below 0.001 mm/year are observed, compared to 0.072 mm/year in conventional ceramic-on-polyethylene (CoPE) and 0.030mm/year in ceramic-on-highly cross-linked PE (CoHXLPE). [3] However, several CoC specific disadvantages are reported, such as squeaking and component fracture of both the head and inlay, which can complicate revision procedures. [4] Moreover, recent literature suggests higher short-term revision rates in CoC bearing due to aseptic loosening compared to CoPE. [5] In a stiffer bearing like CoC, loss of primary stability can occur due to micromotion, making the cup more vulnerable to loosening. Initial stability is also critical for long-term survival of the cup, which remains the weak component in THA. [6,7] The other main reasons for early revision are infection and dislocation, on which the influence of bearing on the short-term remains unclear. [8] In the long-term fewer infections are reported in CoC compared to CoPE at 15 years and fewer revisions due to dislocation in CoC at 9 years. [9,10] In summary, reasons, moments, and rates of revision widely differ between both bearings. Moreover, the incidence of THA with an uncemented cup has rapidly increased over the last years, with an incidence of 34.3% in Sweden, 69.6% in England, Wales, Northern Ireland, and the Isle of Man, 74.4% in The Netherlands and up to 97.1% in Australia. [11-14] Several studies have shown that, regardless of the bearing, uncemented THA decreases long-term aseptic loosening rates, but increases the short-term risk of dislocation, infection, and periprosthetic fracture. [15-17] Compared to the increasing number of press-fit cups placed with Co(HXL)PE and CoC in THA, the number of comparative studies on the aforementioned reasons for revision is still limited. In literature, several reviews have been performed comparing CoC and Co(HXL)PE, but never distinguished in fixation method. [18-21] This finding in combination with the potential influence of bearing on a revision due to loosening in press-fit THA is one of the reasons why we conducted this systematic review. The aim is to investigate if there is a difference in the revision rate of CoC and Co(HXL)PE bearing in THA with a press-fit modular acetabular implant and to investigate if reasons for revision differ between bearings.

Materials and Methods

Search strategy

This systematic review was a priori registered in PROSPERO (registration number: CRD42020206779). During the registration in PROSPERO, we aimed to perform a review focused on (early) aseptic loosening only. Since we recognized that all reasons for revision in press-fit THA are not systematically reviewed, we changed the protocol of the review and included all reasons for the revision. The review was performed in accordance with the Cochrane library recommendations and the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guideline. 22 The search was executed in PubMed (Medline), Embase (Ovid), Cochrane Library, and ClinicalTrials.gov. All studies until 29th July 2021 were included. The search was built with the aid of a clinical librarian and the search strategies are presented in [Appendix 1]. Additionally, reference lists of all included articles were screened for additional eligible articles.

Selection criteria

All comparative randomized and non-randomized, and (national) registry studies investigating CoC and Co(HXL)PE in primary total hip arthroplasty with a press-fit modular cup were included. When multiple bearings, cohorts, or fixations were compared in one study, only the data of press-fit cups with CoC and Co(HXL)PE bearings were included. When different sorts of PE or ceramic generation liners were used in one study, all were combined in respectively one CoPE group and one CoC group. The different sorts of liners included were registered. Studies were excluded if: the patients were younger than 18 years, prior arthroplasty of the affected hip was performed, the cup was cemented, and a screw cup or monobloc or sandwich cup was placed. Since screw fixation is optional in most cups and no difference in revision is reported in the literature between uncemented THA with and without screws, studies using optional additional screws were included as well. [23-25] Studies were excluded if the method of fixation was not mentioned. Systematic reviews, duplicates, and articles presenting data that were too scarce to calculate Hazard ratios for overall revision as the primary outcome were excluded as well. No limitation in publication date or language was enabled. The abstract and full-text screening were performed separately by two independent authors (JL and JG) and disagreements between the two authors were resolved by discussion with a third investigator (KO).

Data extraction

Data was extracted separately by two independent authors (JL and JG) using standardized forms and cross-checked afterward. Disagreements between the two reviewers were resolved by discussion with a third investigator (KO). Collected baseline data included: age, gender, indication for THA (subdivided into primary osteoarthritis, secondary osteoarthritis (avascular necrosis of the femoral head, slipped upper femoral epiphysis, developmental dysplasia of the hip, Perthes disease, rheumatic arthritis, other inflammatory diseases, posttraumatic) or primary traumatic treatment), Body Mass Index (BMI), and follow-up time (in years). Collected surgical data included: cup implant type, cup size, head size, surgical approach, and complications during surgery and postoperative follow-up. Collected revision data included: the number of revision procedures, moments of revision, the different kinds of revision procedures performed, indications for revision, and complication rates of CoC and CoPE. The revision was defined as a procedure by which either the cup, the stem, or both were revised.

Outcomes

As the primary outcome, we will compare the total

number of revisions of CoC and Co (HXL)PE bearing due to all reasons. As secondary outcomes, complication rates and different reasons for revision (loosening, dislocation, infection, postoperative periprosthetic fracture) will be analyzed. All outcomes will be presented and pooled in subgroups based on the study design.

Risk of bias assessment

The risk of bias assessment of the included studies was performed independently by two reviewers (JL and JG), using the Cochrane collaboration's tool for assessing the risk of bias for randomized controlled trials. [26] Studies were scored as having a high (red), unclear (orange), or low (green) risk of bias for the following domains: random sequence generation, allocation concealment, blinding of participants, blinding of the outcome, and attrition bias. For non-randomized cohort and registry studies, the methodological index for non-randomized studies (MINORS) criteria was used. [27] On 12 criteria studies were scored as 'not reported' scoring zero points, 'reported but inadequate' scoring one point, or 'reported and adequate' scoring two points, making the global ideal score 24 points for non-randomized comparative studies. The MINORS were also reported for the RCTs to compare the risk of bias between all studies. Disagreements between the two reviewers were resolved by discussion with a third investigator (KO).

Qualitative analysis

Assessment of the quality of evidence and the strength of the outcomes of all included studies were performed independently by two reviewers (JL and JG) using the Grades of Recommendation Assessment, Development, and Evaluation (GRADE). [28]

Statistical analysis

The study, patient, and clinical characteristics are reported using descriptive statistics. Weighted means with pooled standard deviations (SD) are calculated in the case of continuous variables, and categorical variables are presented as numbers with accompanying proportions. Concerning the primary outcome, crude Hazard Ratios (HR) for revision due to all reasons (CoPE vs CoC) were used to perform the meta-analysis. In case crude HRs were not reported, they were estimated using time-to-event data according to the method of Tierney et al. (2006) or using incidence density rates according to Bender and Beckman (2019), depending on the available data and comparability of observation time. [29,30] HRs were pooled using a random effect model with inverse variance weighting and stratified for study design (RCTs, non-randomized comparative cohort studies, and registry studies). Pooled HRs are presented with 95% confidence intervals (CI).

Additionally, for the studies reporting complications, Risk Ratio (RR) was calculated and pooled by use of a random effect model with inverse variance weighting. Stratification for study design was also performed. Pooled HRs and RRs were considered statistically significant if the 95%CI did not include 1.

Statistical heterogeneity was checked using the I2 value and Chi2 test. A *P>0.1* and an I2 ≤ 50% were interpreted as no statistical heterogeneity. [31] Statistical analyses were performed with R version 4.0.4 (R Foundation for Statistical Computing, Vienna, Austria) using a meta package for meta-analyses. [32] All statistical methods in this study were performed by a biomedical statistical expert. (IS)

Results

Search results

We identified a total of 1109 articles. After title and abstract screening, a total of 128 studies remained. After full-text screening, we included 17 studies in a qualitative synthesis, including 12 randomized controlled trials, three non-randomized comparative studies, and two registry studies. [33-49] The flow chart of the article selection process, including reasons for exclusion based on full-text screening, is shown in [Figure 1]. Three included studies were written by the same author (Pitto et al.), but presented all different study cohorts. [44-46]

Study characteristics

All the selected studies were published between 2001 and 2021. The follow-up ranged from 1.0 to 16.5 years (weighted average of 5.52 years). A total of 38,772 primary THAs with a press-fit modular cup were included, 10,909 with a CoPE bearing (862 in RCTs, 134 in non-randomized comparative studies, 9,913 in registry studies) and 27,863 with a CoC bearing (984 in RCTs, 157 in non-randomized comparative studies, 26,722 in registry studies). The study characteristics of the included studies are shown in [Table 1]. A femoral head size of 28mm was used in all RCTs and cohort studies except two that combined 28mm and 32mm in both bearings. [33,35] The cup size was only reported in two studies: Kim et al. showed a mean cup size of 51.2mm (range, 48–54 mm) in both bearings and van Loon et al. showed a mean cup size of 52.1mm (SD 3.4) in CoPE and 53.6 (SD 3.5) in CoC. [41,49] Focusing on the sort of PE bearing, five (30%) studies used a conventional PE liner, one study (6%) a cross-linked liner, five studies (30%) a highly cross-linked liner, five studies (30%) and ultra-high-molecular-weight liner, and one study (5%) used both conventional and highly cross-linked PE liners. A third-generation ceramic insert was used in eight studies (47%) and five studies (29%) used a fourth-generation ceramic insert. In four studies (24%) the generation and manufacturer of the ceramic insert were not mentioned.

A summary of all HRs and RRs of the primary and secondary outcomes is shown in [Table 1].

Risk of bias

The results of the risk of bias assessment are shown in [Appendix 2] and [Appendix 3] from the perspective of the primary outcome. For the twelve RCTs included, the risk of bias was low in five studies, high in one study, and unclear in six studies. The high risk of bias in one study was due to a difference in the number of patients included in both groups after randomization

and a high loss of follow-up. [33] The unclear risk of bias was mainly related to high loss to follow-up, selective reporting, and limited reporting of blinding and randomization methods. For the non-randomized comparative and registry studies, the main risk of bias was based on the lack of (reporting on) blinding, and not performing sample size calculation and for the registry studies, the high risk of indication bias was due to the methodological design of registry studies.

Qualitative analysis

The strength of evidence for the RCTs was low for the primary outcome and secondary outcomes loosening and infection, due to inconsistency and unclear risk of bias. For dislocation and postoperative periprosthetic fracture, the GRADE strength of evidence was moderate, due to the inconsistency of the included studies. For the non-randomized comparative studies group, the evidence for loosening, dislocation, and the postoperative periprosthetic fracture was very low due to their methodological design and selective reporting of these outcomes by only one study. The evidence of the registry studies was assessed as very low due to the high risk of bias and methodological design. The outcomes of the GRADE quality of evidence assessment are shown in [Table 2].

Primary outcome: overall revision

The total number of revision procedures per study is shown in [Table 3]. The HR for revision of CoPE compared to CoC bearing, is shown in [Figure 2]. The pooled HR for revision was significant in registry studies, with a lower risk of revision in CoPE (HR 0.71 (95%CI 0.53; 0.99)). In RCTs and non-randomized comparative studies, the HR showed a non-significant lower risk of revision in CoC (respectively HR 1.15

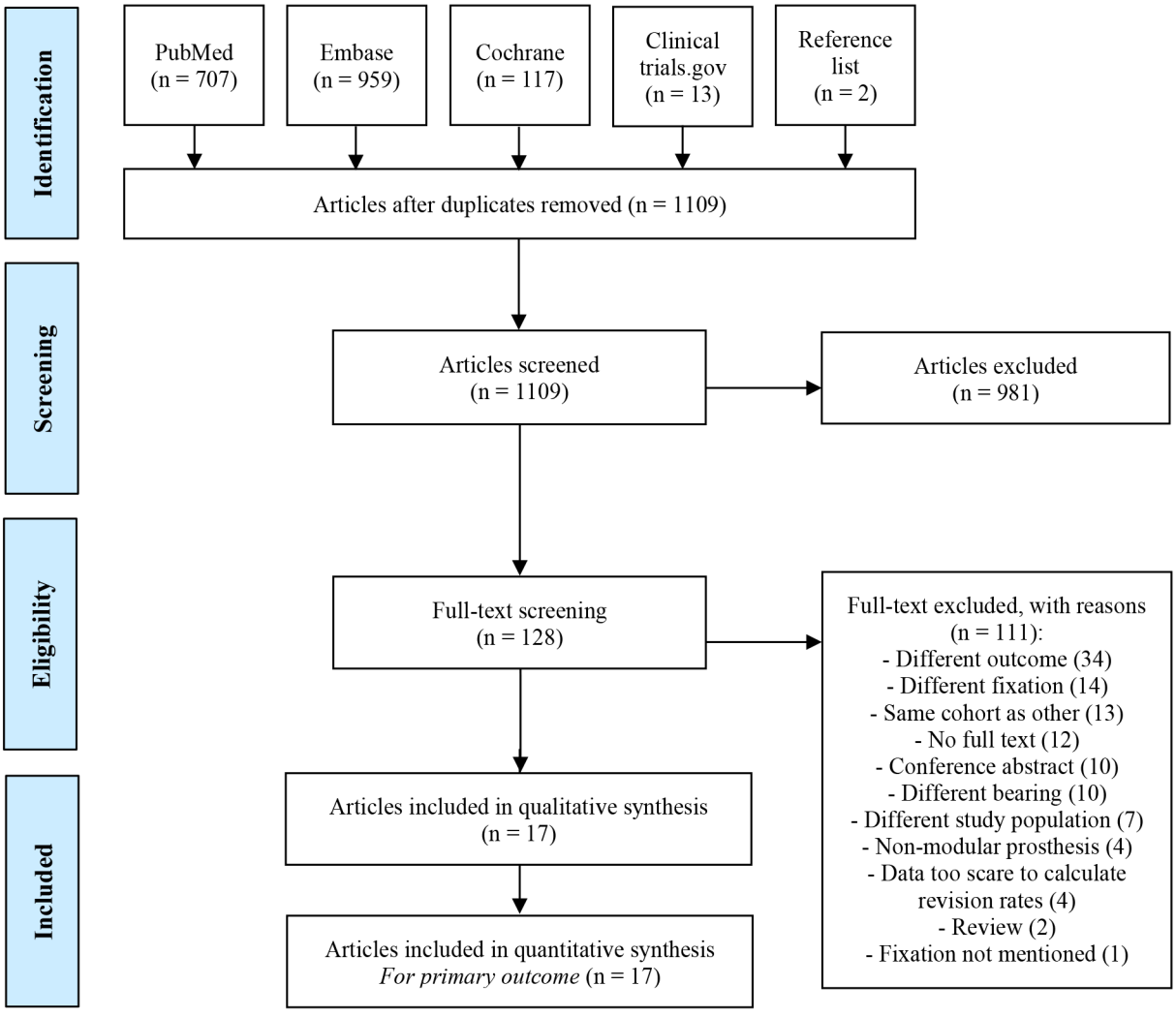

Figure 1. PRISMA flow chart of the article selection process

Table 1. Characteristics of the included study

Study	Bearing	Patients n	THAs n	Age mean (SD)	Female n (%)	BMI mean (SD)	Indication n (%)	Follow-up in years mean (SD)	Surgical approach n (%)	Manufacturer	Head size n (%)
RANDOMIZED CONTROLLED TRIALS											
Atrey (2018)	CoPE[a]	29	29	42.8 (6.9)	16 (55.2)	28.2 (5.2)	POA: 10 (34.5) SOA: 14 (48.3) PT: 5 (17.2)	16.5 (NR)	NR	Reflection, Smith&Nephew	28mm: 29 (100)
	CoC[h]	28	29	41.5 (8.9)	14 (50.0)	26.7 (6.6)	POA: 15 (51.7) SOA: 10 (34.5) PT: 4 (13.8)	16.8 (NR)	NR	Reflection, Smith&Nephew	28mm: 29 (100)
Beaupre (2015)	CoPE[b]	44	44	53.6 (6.5)	20 (45.5)	NR	POA: 10 (34.5)	10.0 (NR)	Post: 29 (65.9) Lat: 15 (34.1)	Secure Fit, Stryker	28mm: 40 (90.9) 32mm: 4 (9.1)
	CoC[h]	44	48	51.3 (6.9)	22 (45.8)	NR	POA: 10 (34.5)	10.0 (NR)	Post: 30 (62.5) Lat: 18 (17.5)	Secure Fit, Stryker	28mm: 9 (18.8)) 32mm: 39 (81.2)
Kim# (2013)	CoPE[c]	100	100	45.3 (NR)	34 (34.0)	23 (NR)	POA: 13 (13.0) SOA: 87 (87.0)	12.4 (NR)	Post: 100 (100)	Duraloc, DePuy	28mm: 100 (100)
	CoC[f]	100	100	45.3 (NR)	34 (34.0)	23 (NR)	POA: 13 (13.0) SOA: 87 (87.0)	12.4 (NR)	Post: 100 (100)	Duraloc, DePuy	28mm: 100 (100)
Cai (2012)	CoPE[d]	50	62	42.0 (10.6)	23 (46.0)	24.8 (4.1)	POA: 13 (21.0) SOA: 49 (79.0)	3.4 (NR)	Post: 62 (100)	T.O.P. press-fit porous-coated TiAl6V4	28mm: 62 (100)
	CoC[g]	43	51	42.1 (10.5)	18 (41.9)	24.6 (3.9)	POA: 11 (21.6) SOA: 40 (78.4)	3.4 (NR)	Post: 51 (100)	T.O.P. press-fit porous-coated TiAl6V4	36mm: 51 (100)
Ama-natullah (2012)	CoPE[d]	146	161	54.7 (12.9)	62 (38.5)	28.0 (5.1)	POA or SOA (numbers NR)	5.0 (NR)	NR	Reflection, Smith&Nephew	28mm: 161 (100)
	CoC[h]	166	196	50.4 (12.8)	60 (36.1)	29.6 (12.4)	POA or SOA (numbers NR)	5.0 (NR)	NR	Reflection, Smith&Nephew	28mm: 61 (31.1) 32mm: 135 (68.9)
Lewis (2010)	CoPE[d]	NR	26	42.8 (6.9)	NR	28.2 (5.2)	POA: 7 (26.9) SOA: 19 (73.1)	8.0 (NR)	Post: 26 (100)	Wright Medical Technology INC	28mm: 26 (100)
	CoC[h]	NR	30	41.5 (8.9)	NR	26.7 (6.6)	POA: 16 (53.3) SOA: 14 (46.7)	8.0 (NR)	Post: 30 (100)	Wright Medical Technology INC	28mm: 30 (100)
Hamilton (2010)	CoPE[c]	87	87	57.3 (NR)	40 (46.0)	NR	POA: 78 (89.7) SOA: 9 (10.3)	2.6 (NR)	Post: 87 (100)	Pinnacle, DePuy	28mm: 87 (100)
	CoC[g]	177	177	56.4 (NR)	87 (49.2)	NR	POA: 155 (87.6) SOA: 22 (12.4)	2.6 (NR)	Post: 177 (100)	Pinnacle, DePuy	28mm: 177 (100)
Pitto (2008)	CoPE[c]	20	20	66.1 (NR)	12 (60.0)	NR	POA: 20 (100)	1.0 (NR)	Lat: 20 (100)	Trilogy, Zimmer	28mm: 20 (100)
	CoC[f]	20	20	64.5 (NR)	13 (65.0)	NR	POA: 20 (100)	1.0 (NR)	Lat: 20 (100)	Trilogy, Zimmer	28mm: 20 (100)
Ochs* (2007)	CoPE[a]	31	31	69.2 (7.2)	NR (33.3)	NR	POA: NR (80.9) SOA: NR (19.1)	7.6 (6.5)	NR	Plasmacup press-fit cup, B.Braun-Aesculap	28mm: 31 (100)
	CoC[f]	35	35	56.0 (7.6)	NR (31.8)	NR	POA: NR (81.8) SOA: NR (18.2)	8.4 (7.2)	NR	Plasmacup press-fit cup, B.Braun-Aesculap	28mm: 35 (100)
Sonny Bal (2005)	CoPE[a]	241	250	60.9 (12.8)	133 (55.2)	NR	POA: 183 (73.2) SOA: 67 (26.8)	2.0 (NR)	NR	CeramTec AG, Plochingen, Germany	28mm: 250 (100)
	CoC[f]	238	250	55.0 (14.7)	112 (47.1)	NR	POA: 160 (64.0) SOA: 90 (36.0)	2.0 (NR)	NR	CeramTec AG, Plochin-gen, Germany	28mm: 250 (100)
Pitto (2003)	CoPE[d]	27	27	NR	NR	NR	POA: 27 (100)	1.1 (NR)	NR	TiRC: Phönix, Brehm, Weisendorf, Germany	28mm: 27 (100)
	CoC[f]	23	23	NR	NR	NR	POA: 23 (100)	1.1 (NR)	NR	TiRC: Phönix, Brehm, Weisendorf, Germany	28mm: 23 (100)

Table 1. Continued

Pitto (2001)	CoPE[a]	24	25	62 (4.5)	16 (66.7)	NR	POA: 25 (100)	5.0 (NR)	NR	TiRC: Phönix, Brehm, Weisendorf, Germany	28mm: 25 (100)
	CoC[f]	25	25	60 (5.5)	15 (60.0)	NR	POA: 25 (100)	5.0 (NR)	NR	TiRC: Phönix, Brehm, Weisendorf, Germany	28mm: 25 (100)
NON-RANDOMIZED COMPARATIVE											
van Loon[p] (2021)	CoPE[a]	27	27	(5.3) 64.2	21 (77.8)	27.6 (4.1)	(POA: 23 (85.2 (SOA: 4 (14.8	(NR) 10.0	(Lat: 27 (100	EP-FIT PLUS, Smith&Nephew	(28mm: 27 (100
	CoC[g]	34	34	(8.5) 55.7	22 (64.7)	26.9 (4.1)	(POA: 19 (55.9 (SOA: 15 (44.1	(NR) 10.0	(Lat: 34 (100	EP-FIT PLUS, Smith&Nephew	(28mm: 34 (100
Feng[r] (2019)	CoPE[c]	62	77	(NR) 59	33 (53.2)	23.2 (NR)	(SOA: 77 (100 *all AVN*	(NR) 7.2	(Post: 77 (100	Pinnacle, DePuy	NR
	CoC[g]	71	93	(NR) 51	40 (56.3)	25.2 (NR)	(SOA: 93 (100 *all AVN*	(NR) 6.9	(Post: 93 (100	Pinnacle, DePuy	NR
Schmidt[p] (2003)	CoPE[d]	30	30	(3.1) 60.0	18 (60.0)	25.1 (2.0)	POA, SOA and PT, numbers NR	(NR) 5.6	(Lat: 30 (100	TiRC: Phönix, Brehm, Weisendorf, Germany	(28mm: 30 (100
	CoC[f]	30	30	(3.3) 58.8	19 (63.3)	24.7 (2.3)	POA, SOA and PT, numbers NR	(NR) 5.6	(Lat: 30 (100	TiRC: Phönix, Brehm, Weisendorf, Germany	(28mm: 30 (100
REGISTRY STUDIES											
Epinette (2016)	CoPE[c]	NR	5232	NR	NR	NR	NR	(NR) 2.1	NR	Trident, Stryker	(32mm: 2521 (48.2=/> (32mm: 2711 (51.8<
	CoC[f]	NR	16182	NR	NR	NR	NR	(NR) 3.8	NR	Trident, Stryker	32mm: 13594=/> ((84.0 (32mm: 2588 (16.0<
Jameson (2013)	CoPE[a,c]	NR	4681	NR	NR	NR	NR	(NR) 5.0	NR	Pinacle, DePuy	NR
	CoC[g]	NR	10540	NR	NR	NR	NR	(NR) 5.0	NR	Pinacle, DePuy	NR

Abbreviations: AVN: avascular necrosis; CoC: Ceramic-on-ceramic CoPE: Ceramic-on-Polyethylene; n = number; Lat: lateral; NR = not reported; POA = primary osteoarthritis; Post: posterior; PT = primary traumatic; SD = standard deviation; SOA = secondary osteoarthritis; THA = Total Hip Arthroplasty; TO = trochanteric osteotomy

* characteristics were reported at final follow-up instead of baseline

Bilateral total hip arthroplasty

a: conventional PE liner, b: cross-linked PE liner, c: highly cross-linked PE liner, d: ultra-high-molecular-weight PE liner, e: sort of PE liner not specified, f: third generation ceramic bearing, g: fourth generation ceramic bearing, h: generation ceramic bearing not specified, p: prospective non-randomized comparative study, r: retrospective non-randomized comparative study

Note: numbers and percentages may not count up to total or 100% due to missing numbers

Table 2. Summary of Hazard Ratio for revision and Risk Ratios for complications of CoPE compared to CoC in modular primary total hip arthroplasty with a press-fit cup and qualitative analysis results

PRIMARY OUTCOME

Complication	No. of studies	Study design	Events CoPE n (%)	Events CoC n (%)	HR (95%CI)	Heterogeneity I^2	GRADE
Revision	12	RCT	25 (2.9)	26 (2.6)	1.15 (0.71; 1.86)	0%	Low
	3	Non-randomized comp	4 (3.0)	2 (1.3)	1.79 (0.41; 7.79)	0%	Low
	2	Registry study	128 (1.3)	489 (1.82)	0.72 (0.53; 0.99)	61%	Very low
SECONDARY OUTCOMES*							
Complication	**No. of studies**	**Study design**	**Events CoPE n (%)**	**Events CoC n (%)**	**RR (95%CI)**	**Heterogeneity I^2**	**GRADE**
Loosening	6	RCT	5 (0.63)	7 (0.76)	0.78 (0.18; 3.32)	0%	Moderate
	1	Non-randomized comp	1 (0.75)	1 (0.64)	1.26 (0.08; 19.22)	Not applicable	Very low
Dislocation	7	RCT	31 (3.92)	28 (3.06)	1.37 (0.82; 2.29)	0%	Moderate
	1	Non-randomized comp	3 (2.24)	6 (3.82)	0.60 (0.16; 2.34)	Not applicable	Very low

Table 2. Continued

Infection	5	RCT	5 (0.63)	9 (1.31)	0.68 (0.23; 1.97)	0%	Moderate
	2	Non-randomized comp	1 (0.75)	1 (0.64)	1.23(0.01; 129.56)	4%	Low
Postoperative peri-prosthetic fracture	3	RCT	2 (0.25)	9 (0.98)	0.29 (0.06; 1.31)	0%	Moderate
	1	Non-randomized comp	1 (0.75)	0 (0)	13.28 (0.02; 8452.09)	Not applicable	Very low

GRADE: High quality: Further research is very unlikely to change our confidence in the estimate of effect. There are sufficient data with narrow confidence intervals. There are no known or suspected reporting biases. Moderate quality: Further research is likely to have an important impact on confidence in the estimate of effect and may change the estimate; one of the domains is not met. Low quality: Further research is very likely to have an important impact on confidence in the estimate of effect and is likely to change the estimate; two of the domains are not met. Very low quality: Great uncertainty about the estimate; three of the domains are not met.
* Secondary outcomes were not reported separately per bearing by the included registry studies

(95%CI 0.71; 1.86) and HR 1.79 (95%CI 0.41; 7.79)).

Secondary outcomes: complications and reasons for revision

An overview of the surgical and postoperative complications and reasons for revision are shown in [Table 3] and [Appendix 4, Appendix 5, Appendix 6, and Appendix 7]. No registry studies mentioned the secondary outcomes separately per bearing and are therefore not reported for this study design.

Table 3. Complications duri Table 3. Complications during surgery, postoperative, and reasons for revision ng surgery, postoperative, and reasons for revision

Study	Bearing	Patients *n*	THAs *n*	Surgical complications *n (%)*	Post-operative complications *n (%)*	Number of revisions *n (%)*	Reasons for revision *n (%)*	Moment of revision
RANDOMIZED CONTROLLED TRIALS								
Atrey (2018)	CoPE[a]	29	29	NR	Wear: 4 (13.8) Pain: 1 (3.4)	5 (17.2)	Wear: 4 (13.8) Pain: 1 (3.4)	Mean 16 yr
	CoC[h]	28	29	NR	Aseptic loosening cup: 1 (3.4) Head fracture: 1 (3.4) Infection (septic): 1 (3.4) Trunnionosis: 1 (3.4)	4 (13.7)	Aseptic loosening cup: 1 (3.4) Head fracture: 1 (3.4) Infection (septic): 1 (3.4) Trunnionosis: 1 (3.4)	15 yr 14 yr 13 yr 14 yr
Beaupre (2015	CoPE[b]	44	44	NR	Dislocation: 5 (11.4)	3 (6.8)	Recurrent dislocation: 3 (6.8)	<5 yr (2x), 7yr
	CoC[h]	48	48	NR	Dislocation: 2 (4.2) Periprosthetic fracture: 1 (2.1)	0 (0)	-	NR
Kim[#] (2013)	CoPE[c]	100	100	NR	Dislocation: 1 (1.0)	1 (1.0)	Recurrent dislocation: 1 (1.0)	NR
	CoC[f]	100	100	Periprosthetic fracture: 2 (2.0)	Squeaking: 13 (13.0) Dislocation: 1 (1.0)	1 (1.0)	Recurrent dislocation: 1 (1.0)	NR
Cai (2012)	CoPE[d]	50	62	Periprosthetic fracture: 1 (1.6)	Osteolysis stem: 3 (4.8) Dislocation: 2 (3.2) Deep vein thrombosis: 1 (1.6) Leg length discrepancy: 1 (1.6)	3 (4.8)	Aseptic loosening cup: 1 (1.6) Leg length discrepancy: 1 (1.6) Recurrent dislocation: 1 (1.6)	NR
	CoC[g]	43	51	Liner fracture: 1 (2.0)	Squeaking: 2 (3.9) Delayed wound healing: 1 (1.9) Dislocation: 1 (1.9) Infection: 1 (1.9)	2 (3.9)	Infection: 1 (1.9) Recurrent dislocation: 1 (1.9)	NR
Ama-natullah (2012)	CoPE[d]	146	161	Periprosthetic fracture: 1 (0.6)	Heterotopic ossification: 41 (25.5) Dislocation: 9 (5.6) Trochanteric bursitis: 5 (3.1) Infection: 5 (3.1) Deep vein thrombosis: 2 (1.2) Migration: 2 (1.2) Pulmonary embolism: 1 (0.6) Leg length discrepancy: 1 (0.6) Wear: 1 (0.6)	3 (1.9)	Recurrent dislocation: 2 (1.2) Infection: 1 (0.6)	Before dis-charge, 5yr NR

Table 3. Continued

	CoC[h]	166	196	Liner fracture: 2 (1.0) Periprosthetic fracture: 1 (0.5) Sciatic nerve injury: 1 (0.5)	Heterotopic ossification: 59 (30.1) Dislocation: 10 (5.6) Infection: 7 (3.6) Squeaking: 6 (3.1) Migration: 4 (2.0) Deep vein thrombosis: 3 (1.5) Pulmonary embolism: 2 (1.0) Liner fracture: 2 (1.0) Leg length discrepancy: 2 (1.0) Head fracture: 1 (0.5) Wear: 1 (0.5)	11 (5.6)	Recurrent dislocation: 4 (2.0) Aseptic loosening stem: 3 (1.5) Liner fracture: 2 (1.0) Head fracture: 1 (0.5) Infection: 1 (0.5)	3mo, 6mo, 1yr, 4yr NR 3 yr, 5 yr 2 yr 3 mo
Lewis (2010)	CoPE[d]	NR	26	Periprosthetic fracture: 2 (7.7)	NR	1 (3.8)	Pain: 1 (3.8)	6 yr
	CoC[h]	NR	30	Periprosthetic fracture: 1 (3.3)	Dislocation: 1 (3.3)	1 (3.3)	Recurrent dislocation: 1 (3.3)	4 yr
Hamilton (2010)	CoPE[c]	87	87	Periprosthetic fracture: 1 (1.1)	Delayed wound healing: 2 (2.3) Dislocation: 4 (4.6)	2 (2.3)	Recurrent dislocation: 2 (2.3)	NR
	CoC[g]	177	177	Periprosthetic fracture: 5 (2.8) Liner fracture: 1 (0.6) Nerve injury: 1 (0.6)	Delayed wound healing: 9 (7.7) Dislocation: 5 (2.8) Osteolysis stem: 3 (1.7) Infection: 2 (1.1) Liner fracture: 2 (1.1) Periprosthetic fracture: 2 (1.1)	5 (2.8)	Aseptic loosening stem: 2 (1.1) Liner fracture: 1 (0.6) Infection: 2 (1.1)	NR
Pitto (2008)	CoPE[c]	20	20	NR	NR	0 (0)	-	NR
	CoC[f]	20	20	NR	NR	0 (0)	-	NR
Ochs* (2007)	CoPE[a]	31	31	NR	Femoral nerve weakness: 2 (6.5) Deep vein thrombosis: 1 (3.2)	1 (3.2)	Aseptic loosening cup: 1 (3.2)	1 week
	CoC[f]	35	35	NR	Dislocation: 1 (2.9) Infection: 1 (2.9)	1 (2.9)	Infection: 1 (2.9)	NR
Sonny Bal (2005)	CoPE[a]	241	250	NR	Dislocation: 10 (4.0) Deep vein thrombosis: 4 (1.6) Delayed wound healing: 4 (1.6) Leg length discrepancy: 2 (0.8) Periprosthetic fracture: 2 (0.8)	6 (2.4)	Recurrent dislocation: 5 (2.0) Aseptic loosening cup: 1 (0.4)	NR
	CoC[f]	238	250	Liner fracture: 1 (0.4)	Dislocation: 7 (2.8) Periprosthetic fracture: 6 (2.4) Delayed wound healing: 5 (2.0) Deep vein thrombosis: 4 (1.6)	1 (0.4)	Recurrent dislocation: 1 (0.4)	NR
Pitto (2003)	CoPE[d]	27	27	NR	NR	0 (0)	-	NR
	CoC[f]	23	23	NR	NR	0 (0)	-	NR
Pitto (2001)	CoPE[a]	24	25	NR	NR	0 (0)	-	NR
	CoC[f]	25	25	NR	NR	0 (0)	-	NR
NON-RANDOMIZED COMPARATIVE STUDIES								
van Loon[p] (2021)	CoPE[a]	27	27	Periprosthetic fracture: 1 (3.7)	Delayed wound healing: 2 (7.4) Peroneal nerve injury: 2 (7.4)	3 (11.1)	Wear: 2 (7.4) Aseptic loosening stem 1 (3.7)	NR
	CoC[g]	34	34	Periprosthetic fracture: 2 (25.8)	Delayed wound healing: 4 (11.7)	2 (5.9)	Aseptic loosening stem 1 (2.9) Infection (late): 1 (2.9)	NR

Table 3. Continued

Feng[r] (2019)	CoPE[c]	62	77	NR	Dislocation: 3 (3.9) Squeaking: 2 (2.6) Periprosthetic fracture: 1 (1.3) Infection: 1 (1.3)	1 (1.3)	Periprosthetic fracture: 1 (1.3)	NR
	CoC[g]	71	93	NR	Squeaking: 8 (8.6) Dislocation: 6 (6.5)	0 (0)	-	N/A
Schmidt[p] (2003)	CoPE[d]	30	30	NR	0 complications	0 (0)	-	N/A
	CoC[f]	30	30	NR	0 complications	0 (0)	-	N/A
REGISTRY STUDIES								
Epinette (2016)	CoPE[c]	NR	5232	NR	NR	46 (0.9)	Not specified	NR
	CoC[f]	NR	16182	NR	NR	273 (1.7)	Not specified	NR
Jameson (2013)	CoPE[a,c]	NR	4681	NR	NR	82 (1.8)	Not specified	NR
	CoC[g]	NR	10540	NR	NR	216 (2.1)	Not specified	NR

Abbreviations: CoC: Ceramic-on-ceramic CoPE: Ceramic-on-Polyethylene; n = number; NR = not reported; THA = Total Hip Arthroplasty;
* characteristics were reported at final follow-up instead of baseline
# Bilateral total hip arthroplasty
a: conventional PE liner, b: cross-linked PE liner, c: highly cross-linked PE liner, d: ultra-high-molecular-weight PE liner, e: sort of PE liner not specified, f: third generation ceramic bearing, g: fourth generation ceramic bearing, h: generation ceramic bearing not specified, p: prospective non-randomized comparative study, r: retrospective non-randomized comparative study
Note: numbers and percentages may not count up to total or 100% due to missing numbers

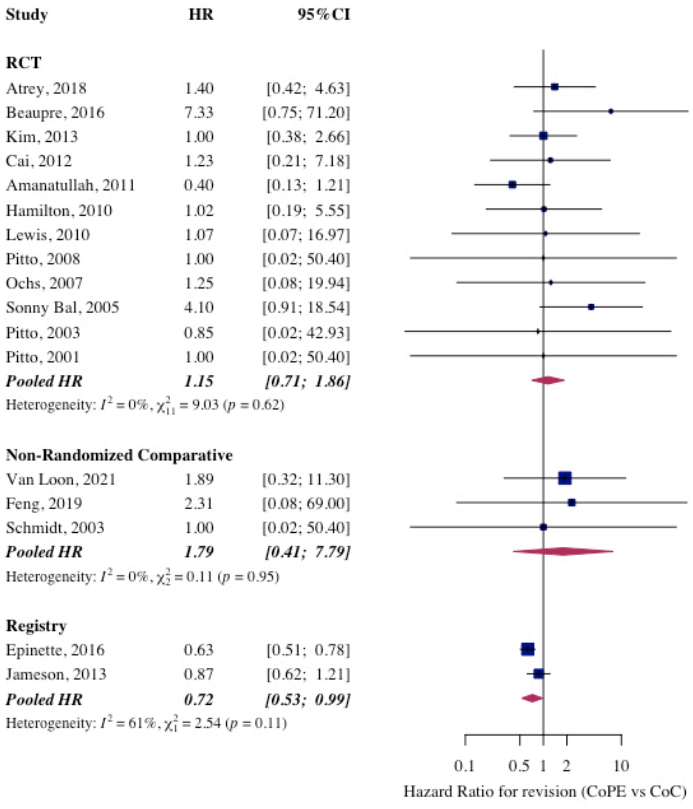

Figure 1. Hazard ratio (HR) for revision in modular primary total hip arthroplasty with a press-fit cup of CoPE compared to CoC bearing.

All outcomes (loosening, dislocation, infection postoperative periprosthetic fracture), showed no significant difference in the risk of revision. One study reported migration of components without loosening, with an incidence of 2.0% in CoC and 1.2% in CoPE. [33]

Bearing related complications or reasons for revision

The squeaking was described in three RCTs in CoC only with an incidence of respectively 13.0%, 3.9%, and 3.1%. [33,36,41] In one nonrandomized cohort study squeaking was reported with an incidence of 2.6% in CoPE and 8.6% in CoC. [38] Another component-related complication was wear, which was reported by two RCTs. [33,34] An incidence of PE wear of 13.8% and 0.6% respectively were observed, whereas the last-mentioned study also reported wear in 0.5% of the CoC THAs. One cohort study reported wear in CoPE with an incidence of 7.4%. [49] Fracture of the ceramic liner was reported during surgery in four RCTs with an incidence of respectively 2.0%, 1.0%, 0.6%, and 0.4%. [33,36,39,48] Fracture of ceramic components was seen in three RCTs. 33,34,39 One study showed an incidence of 3.4% in CoC of the ceramic head, one study showed an incidence of 0.6% of the ceramic liner, whereas the last study showed fractures of both the head and liner with an incidence of respectively 0.5% and 1.0% in CoC. [33,34,39] The last bearing-related complication was trunnionosis, which was seen in one RCT in CoC with an incidence of 3.4%. [34]

Discussion

This systematic review and meta-analysis showed a significantly lower risk of cup revision in primary THA with a press-fit modular cup using CoPE bearing compared to CoC in registry studies, based on very low-quality GRADE evidence. The RCTs and non-randomized comparative studies showed no difference, based on low-quality GRADE evidence. Since this outcome is based on only two registry studies and RCTs and non-randomized comparative studies showed no difference, this result should be considered preliminary. In literature, four other systematic reviews comparing both bearings were identified and showed similar results. [18-21] However, these reviews investigated RCTs only, included fewer RCTs, or did not distinguish in fixation method. [18-21] The most recent review investigated only CoHXLPE bearing and included fewer studies but two different from our. [18] One of these studies used a zirconium head and the other a sandwich cup, making both studies not suitable for our inclusion. Registry studies did not split complications and reasons for revision and since this methodological study type was the only one showing a difference in overall revision, this could explain why our study showed no difference on the secondary outcomes: complications and reasons for revision. To our knowledge, this is the first systematic review focused on the revision between CoC and Co(HXL)PE bearing in press-fit cups only in THA.

Focused on loosening as a reason for revision, no significant differences were observed. The aforementioned systematic reviews supported this outcome by showing no difference in loosening as well. [18-21] Recent literature suggests that more early aseptic loosening occurs in CoC, due to the influence of the stiff bearing on osseointegration during the transition from primary to definitive stability. [5] In long-term, the main reason for revision in literature remains aseptic loosening based on wear-induced osteolysis of PE. [2] That no difference was found in this review could be attributed to the difference in follow-up time between studies.

Dislocation showed no significant difference in all study designs. In line with three of the abovementioned reviews that investigated dislocation, we found a trend of a lower risk of dislocation in CoC bearing in RCTs, which was not significant. [19-21] Most included studies reported the use of larger femoral head size in CoC, which is used more often in CoC due to the correlation of bigger head size with higher volumetric wear in CoPE. [50] A bigger head size increases the range of motion as well, which results in a lower chance of impingement and hereby fewer dislocations in CoC. [51] Nevertheless, the included studies showed a surprisingly high incidence of 28mm small heads being used, which might declare the high rates of dislocation in some of the studies. The highest RR of Beaupre et al. showed a lower risk of dislocation in CoC as well. [35] The long-term follow-up and use of cross-linked PE instead of HXLPE in this study both increase the risk of wear and hereby the long-term risk of dislocation. [52] The difference between studies in follow-up time and types of PE inlay might be the reason why the RR of dislocation differed between studies and no difference was observed after pooling.

The infection showed no significant difference between bearings, which was supported by three of the abovementioned reviews that investigated infection. [19-21] A recent German registry study showed a significantly lower risk of revision for periprosthetic joint infection (PJI) at three years follow-up for CoC compared to CoPE using propensity score matching analysis. [53] Unfortunately, no crude data was available about the overall revision rates to include this study in our analysis. Nevertheless, their outcomes on infection as the reason for revision are important to keep in mind when choosing a bearing. In addition, Pitto et al. showed a lower risk of infection in CoC on long-term. [10] One of the theories to explain this difference is that higher hydrophilicity and wettability in CoC results in a lower bacterial attachment to the bearing. As mentioned in both studies, more long-term follow-up research and microbiologic data are needed to confirm the potential benefits of CoC on PJI in THA.

Postoperative periprosthetic fracture showed no difference between bearings, but a trend of a lower risk of periprosthetic fracture in CoPE. In literature, the higher incidence of wear-induced osteolysis and difference in the mechanical transmission of forces on the stem, are presumed to result in a different biologic response in a more elastic CoPE bearing, which might result in a lower risk of periprosthetic fracture. [54]

Focused on bearing-related complications, squeaking

was mostly reported in CoC and widely differed between studies. This was supported by three of the previously mentioned systematic reviews investigating squeaking. [19-21] The difference between studies might be explained by the generation of the ceramic liner, since a third-generation ceramic liner showed an incidence of 13.0%, compared to a fourth-generation liner with an incidence of 3.9% and 2.6% in two studies. [36,38,41] A recent registry study comparing revisions between both generations showed six revisions (6.5%) in a third generation because of squeaking and zero out of 54 (0.0%) in a fourth-generation. [55] Several studies investigated the phenomenon of squeaking, but its etiology is still a point of discussion. One of the main reasons for squeaking to occur might be disruption of fluid lubrication, which can be caused by a lack of fluid or particles between the head and cup. [56] Factors influencing this process are patient factors, for example, BMI, implant characteristics, implant positioning, and biomechanical factors, like wear, extreme loading, or micro-fractures. [57,58] Although wear in CoC is limited, the fourth-generation ceramic bearings were invented to improve wear properties and improve its resistance against (micro-)fractures, achieved using a slightly different alloy and a different manufacturing process. [57,59] Although squeaking is a multifactorial problem with a wide variation of incidence in literature, the improved features of the fourth-generation ceramics might declare the difference in the incidence of squeaking in our study.

Another bearing-related complication is a ceramic head or liner fracture, which was mostly seen in CoC, but only reported by a few studies. Although ceramic fracture is one of the greatest concerns of the use of this articulation, a recent meta-analysis showed that improvement of the ceramic leads to less ceramic fracture. [4] Compared to the incidence of wear as a complication of Co(HXL)PE, the incidence of both complications was more or less comparable. Although wear is improved by the process of (highly) cross-linking in CoPE bearing, CoC bearings hold a potential to decrease wear up to wear rates below 0.001 mm/year. [3] Wear was unfortunately only reported by two studies, in which the highest incidence was seen in a conventional PE liner with 16.5 years follow-up. [34] To adequately investigate ceramic fracture and PE wear, more long-term research is needed in the same sort of PE liners and same-generation ceramic bearings, since the incidence of both complications will increase over time.

Another important factor to keep in mind when choosing a bearing is the cost of CoC which is three times more expensive than CoPE. [35] In all studies, CoC was placed in younger patients, except for the study of Cai et al. [36] In addition, the prevalence of THA increases with a shift to a younger age, combined with a still increasing life expectancy. [60] Hereby, the performance of the implant needs to prove itself for a longer period and in more active younger people. This is comparable to the in vitro hip simulation study of De Fine et al., in which in the worst-case wear scenario CoC outstands CoHXLPE. [61] The abovementioned revision rates and complications need to be considered when choosing a bearing.

Strengths

This is to our knowledge the first review to report on press-fit cups in THA only. Moreover, it is the first review to report both RCTs and non-randomized comparative and registry studies on this subject. We used the PRISMA statement guidelines, Cochrane risk of bias assessment, MINORS risk of bias assessment, and the GRADE level of evidence tool to assess the quality of evidence, to provide a transparent method of reporting the best available evidence on this subject and provide a more objective interpretation of our results.

Limitations

The statistical heterogeneity of our results was high in registry studies due to big cohorts with small 95%CI and only two studies included. This resulted in an HR with a wide 95%CI which was slightly significant, which is important when interpreting this result. Clinical heterogeneity was seen due to several kinds of bias. An important limitation was the risk of lead time bias, due to differences in follow-up time between the different studies and this bias might be present between subjects in registry studies as well. This can influence the incidence of several complications or reasons for revision and more important, bearing-related complications like wear and ceramic fracture. This increases the risk of outcome bias as well, which is also increased since we combined all sorts of PE bearings, which can have an influence on the incidence of wear-related reasons for the revision. Another limitation was baseline imbalance since we were not able to perform correction for baseline characteristics, which can influence the incidence of complications and reasons for revision. Another potential difference in the baseline is an incidence of screw fixation, since several studies mentioned the option of potential screw fixation, without reporting the number of THAs placed with additional screws. [35,36,39,48] Another clinical limitation is that loosening was not split between the cup and stem in most studies, excluding analysis of potential differences between bearings. Methodological heterogeneity was seen in the included registry studies, since these only report on complications leading to revision, the total number of complications may be underestimated and can differ from other study designs. At last, reasons for revision in registry studies were often not broken down by bearing or fixation, limiting the amount of included registry studies.

The lower risk of overall revision in registry studies of primary THA with a press-fit modular cup using CoPE bearing compared to CoC should be considered preliminary since this outcome was just slightly significant, based on very quality low-quality GRADE evidence and based on only two studies with several limitations. Since no difference was observed in

the other methodological designs and the separate reasons for revision showed no significant difference in all designs either, no preference for CoC or CoPE can be expressed, and therefore both seem suitable options based on the available literature.

More comparative long-term studies are needed to confirm the potential advantages of wear-reduction of both bearings since the currently available literature is limited.

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Appendix 1. Search Strategy

PubMed (Medline):

("Arthroplasty, Replacement, Hip"[Mesh] OR "Hip Prosthesis"[Mesh] OR THA[tiab]) OR (("Arthroplasty"[Mesh:NoExp] OR "Arthroplasty, Replacement"[Mesh] OR "Prostheses and Implants"[Mesh:NoExp] OR "Joint Prosthesis"[Mesh:NoExp] OR "Hip Prosthesis"[Mesh] OR arthroplast*[tiab] OR replacement*[tiab] OR prosthes*[tiab]) AND ("Hip Joint"[Mesh] OR "Hip"[Mesh] OR hip[tiab] OR hips[tiab])) AND ("Ceramics"[Mesh] OR ceramic*[tiab] OR alumina[tiab] OR CoC[tiab] OR biolox*[tiab]) AND ("Polyethylenes"[Mesh] OR polyethylene*[tiab] OR poly ethylene*[tiab] OR polytene*[tiab] OR polythene*[tiab] OR CoPE[tiab] OR CoHXLPE[tiab]) AND ("Treatment Outcome"[Mesh] OR "Prognosis"[Mesh:NoExp] OR aseptic[tiab] OR loosening[tiab] OR revision*[tiab] OR reoperat*[tiab] OR survival[tiab] OR failure*[tiab] OR complication*[tiab])

EMBASE (OVID):

#	Searches
1	arthroplasty/ or total arthroplasty/ or exp hip arthroplasty/ or replacement arthroplasty/ or exp hip replacement/ or exp "orthopedic prosthesis and orthosis"/ or joint prosthesis/ or exp hip prosthesis/ or (arthroplast* or replacement* or prosthes*).ti,ab,kw.
2	exp hip/ or (hip or hips).ti,ab,kw.
3	1 and 2
4	exp total hip prosthesis/ or THA.ti,ab,kw.
5	3 or 4
6	ceramics/ or ceramic prosthesis/
7	(ceramic* or alumina or CoC or biolox).ti,ab,kw.
8	6 or 7
9	polyethylene/ or polyethylene derivative/
10	(polyethylene* or poly ethylene* or polytene* or polythene* or CoPE or CoHXLPE).ti,ab,kw.
11	9 or 10
12	treatment outcome/ or exp treatment failure/ or prognosis/ or prosthesis complication/ or exp prosthesis loosening/
13	(aseptic or loosening or revision* or reoperat* or survival or failure* or complication*).ti,ab,kw.
14	12 or 13
15	5 and 8 and 11 and 14

Cochrane Library

ID	Search
#1	((arthroplast* or replacement* or prosthes*) and (hip*)):ti,ab,kw
#2	(THA):ti,ab,kw
#3	#1 or #2
#4	(ceramic* or alumina or CoC or biolox):ti,ab,kw
#5	(polyethylene* or poly ethylene* or polytene* or polythene* or CoPE or CoHXLPE):ti,ab,kw
#6	#3 and #4 and #5

ClinicalTrials.gov

hip arthroplasty | ceramic* or polyethylene*

Appendix 2. Quality assessment of the risk of bias, a summary of the included randomized controlled trials

Appendix 3. Quality assessment of the risk of bias, a summary of the included cohort and registry studies

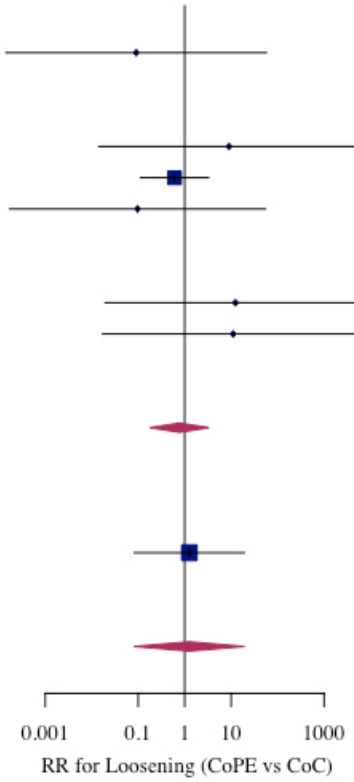
Study	Methodological items for non-randomized studies score (MINORS) *												Total #
	1	2	3	4	5	6	7	8	9	10	11	12	
RCT													
Atrey et al. (2018)	0	2	2	1	0	2	1	2	2	2	1	1	**16**
Beaupre et al. (2016)	2	2	2	2	0	2	1	0	2	2	2	2	**19**
Kim et al. (2013)	2	1	2	2	1	2	2	2	2	2	0	2	**20**
Cai et al. (2012)	2	2	2	2	0	2	0	0	2	2	2	1	**17**
Amanatullah et al. (2011)	2	2	2	1	1	2	1	0	2	2	1	1	**17**
Hamilton et al. (2010)	2	2	2	2	0	2	2	2	2	2	2	1	**21**
Lewis et al. (2010)	2	2	2	2	1	2	2	0	2	2	1	1	**19**
Pitto et al (2008)	2	2	2	1	1	2	1	2	2	2	2	1	**20**
Ochs et al. (2007)	2	2	2	1	1	2	1	0	2	2	1	1	**17**
Sonny Bal et al. (2005)	2	1	2	2	2	2	1	1	2	2	1	1	**19**
Pitto et al (2003)	2	1	2	1	0	2	1	0	2	2	0	1	**14**
Pitto et al (2001)	2	2	2	1	0	2	1	1	2	2	0	1	**16**
Non-randomized comparative studies													
van Loon et al. (2021)	2	2	2	1	0	2	1	0	2	2	1	2	**17**
Feng et al. (2019)	2	1	2	1	0	2	2	0	2	2	1	1	**16**
Schmidt et al. (2003)	1	2	2	2	1	2	2	0	2	2	2	1	**19**
Registry studies													
Epinette et al. (2016)	2	2	2	2	0	2	2	0	2	2	1	2	**19**
Jameson et al. (2013)	2	2	2	2	0	2	2	0	2	2	0	2	**18**

* The items are scored 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate).
# The global ideal score being 16 for non-comparative studies and 24 for comparative studies

1. A clearly stated aim: the question addressed should be precise and relevant in the light of available literature
2. Inclusion of consecutive patients: all patients potentially fit for inclusion (satisfying the criteria for inclusion) have been included in the study during the study period (no exclusion or details about the reasons for exclusion)
3. Prospective collection of data: data were collected according to a protocol established before the beginning of the study
4. Endpoints appropriate to the aim of the study: unambiguous explanation of the criteria used to evaluate the main outcome which should be in accordance with the question addressed by the study. Also, the endpoints should be assessed on an intention-to-treat basis.
5. Unbiased assessment of the study endpoint: blind evaluation of objective endpoints and double-blind evaluation of subjective endpoints. Otherwise the reasons for not blinding should be stated
6. Follow-up period appropriate to the aim of the study: the follow-up should be sufficiently long to allow the assessment of the main endpoint and possible adverse events
7. Loss to follow up less than 5%: all patients should be included in the follow up. Otherwise, the proportion lost to follow up should not exceed the proportion experiencing the major endpoint
8. Prospective calculation of the study size: information of the size of detectable difference of interest with a calculation of 95% confidence interval, according to the expected incidence of the outcome event, and information about the level for statistical significance and estimates of power when comparing the outcomes
9. An adequate control group: having a gold standard diagnostic test or therapeutic intervention recognized as the optimal intervention according to the available published data
10. Contemporary groups: control and studied group should be managed during the same time period (no historical comparison)
11. Baseline equivalence of groups: the groups should be similar regarding the criteria other than the studied endpoints. Absence of confounding factors that could bias the interpretation of the results
12. Adequate statistical analyses: whether the statistics were in accordance with the type of study with calculation of confidence intervals or relative risk

Appendix 4. Relative risk (RR) for loosening of components during follow-up of CoPE compared to CoC in modular primary total hip arthroplasty with a press-fit cup

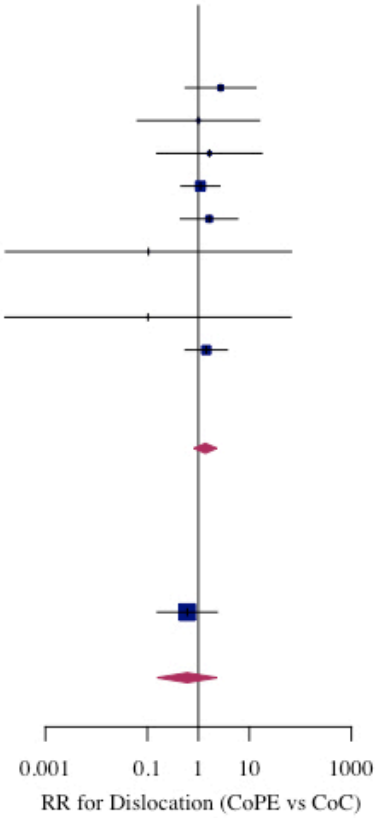
Study	Experimental Event CoPE	Experimental No CoPE	Control Event CoC	Control No CoC	RR	95%CI
RCT						
Atrey, 2018	0	29	1	29	0.09	[0.00; 57.70]
Beaupre, 2016	0	44	0	48		
Kim, 2013	0	100	0	100		
Cai, 2012	1	62	0	51	9.05	[0.01; 5803.72]
Amanatullah, 2011	2	161	4	196	0.61	[0.11; 3.28]
Hamilton, 2010	0	87	2	177	0.10	[0.00; 54.77]
Lewis, 2010	0	26	0	30		
Pitto, 2008	0	20	0	20		
Ochs, 2007	1	31	0	35	12.41	[0.02; 7895.97]
Sonny Bal, 2005	1	250	0	250	11.00	[0.02; 7108.67]
Pitto, 2003	0	27	0	23		
Pitto, 2001	0	25	0	25		
Pooled RR		**862**		**984**	**0.78**	**[0.18; 3.32]**
Heterogeneity: $I^2 = 0\%$, $\chi^2_5 = 2.83$ ($p = 0.73$)						
Non-Randomized Comparative						
Van Loon, 2021	1	27	1	34	1.26	[0.08; 19.22]
Feng, 2019	0	77	0	93		
Schmidt, 2003	0	30	0	30		
Pooled RR		**134**		**157**	**1.26**	**[0.08; 19.22]**
Heterogeneity: not applicable						



Note: not estimable RR due to no events in both subgroups are left empty

Appendix 5. Relative risk (RR) for dislocation during follow-up of CoPE compared to CoC in modular primary total hip arthroplasty with a press-fit cup

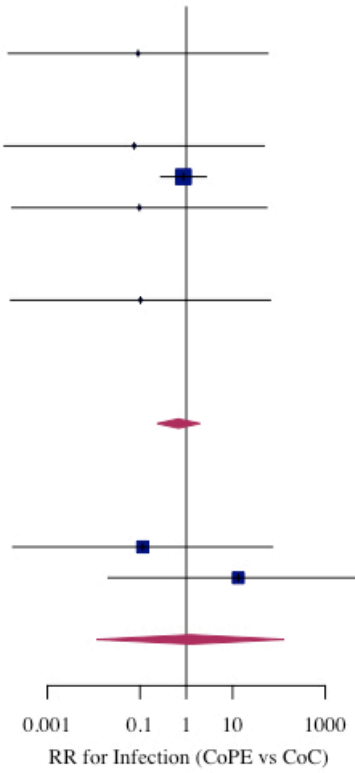
Study	Experimental Event CoPE	Experimental No CoPE	Control Event CoC	Control No CoC	RR	95%CI
RCT						
Atrey, 2018	0	29	0	29		
Beaupre, 2016	5	44	2	48	2.73	[0.56; 13.35]
Kim, 2013	1	100	1	100	1.00	[0.06; 15.77]
Cai, 2012	2	62	1	51	1.65	[0.15; 17.63]
Amanatullah, 2011	9	161	10	196	1.10	[0.46; 2.63]
Hamilton, 2010	4	87	5	177	1.63	[0.45; 5.91]
Lewis, 2010	0	26	1	30	0.10	[0.00; 66.49]
Pitto, 2008	0	20	0	20		
Ochs, 2007	0	31	1	35	0.10	[0.00; 65.28]
Sonny Bal, 2005	10	250	7	250	1.43	[0.55; 3.69]
Pitto, 2003	0	27	0	23		
Pitto, 2001	0	25	0	25		
Pooled RR		**862**		**984**	**1.37**	**[0.82; 2.29]**
Heterogeneity: $I^2 = 0\%$, $\chi^2_7 = 2.35$ ($p = 0.94$)						
Non-Randomized Comparative						
Van Loon, 2021	0	27	0	34		
Feng, 2019	3	77	6	93	0.60	[0.16; 2.34]
Schmidt, 2003	0	30	0	30		
Pooled RR		**134**		**157**	**0.60**	**[0.16; 2.34]**
Heterogeneity: not applicable						



Note: not estimable RR due to no events in both subgroups are left empty

Appendix 6. Relative risk (RR) for infection during follow-up of CoPE compared to CoC in modular primary total hip arthroplasty with a press-fit cup

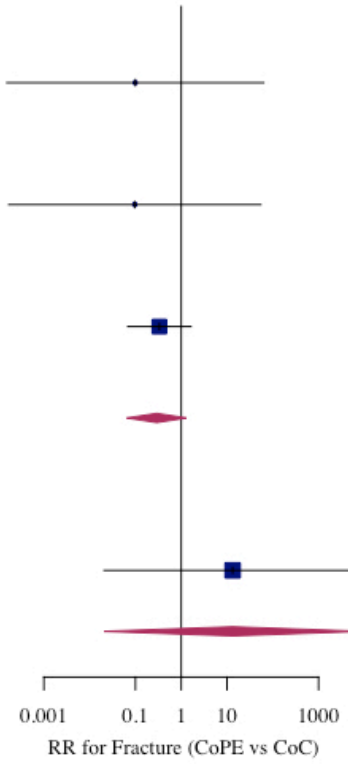
Study	Experimental Event CoPE	Experimental No CoPE	Control Event CoC	Control No CoC	RR	95%CI
RCT						
Atrey, 2018	0	29	1	29	0.09	[0.00; 57.70]
Beaupre, 2016	0	44	0	48		
Kim, 2013	0	100	0	100		
Cai, 2012	0	62	1	51	0.07	[0.00; 47.96]
Amanatullah, 2011	5	161	7	196	0.87	[0.28; 2.69]
Hamilton, 2010	0	87	2	177	0.10	[0.00; 54.77]
Lewis, 2010	0	26	0	30		
Pitto, 2008	0	20	0	20		
Ochs, 2007	0	31	1	35	0.10	[0.00; 65.26]
Sonny Bal, 2005	0	250	0	250		
Pitto, 2003	0	27	0	23		
Pitto, 2001	0	25	0	25		
Pooled RR		**862**		**984**	**0.68**	**[0.23; 1.97]**
Heterogeneity: $I^2 = 0\%$, $\chi^2_4 = 1.7$ ($p = 0.79$)						
Non-Randomized Comparative						
Van Loon, 2021	0	27	1	34	0.11	[0.00; 72.61]
Feng, 2019	1	77	0	93	13.28	[0.02; 8542.09]
Schmidt, 2003	0	30	0	30		
Pooled RR		**134**		**157**	**1.23**	**[0.01; 129.56]**
Heterogeneity: $I^2 = 4\%$, $\chi^2_1 = 1.04$ ($p = 0.31$)						



Note: not estimable RR due to no events in both subgroups are left empty

Appendix 7. Relative risk (RR) for postoperative periprosthetic fractures during follow-up of CoPE compared to CoC in modular primary total hip arthroplasty with a press-fit cup

Study	Experimental Event CoPE	Experimental No CoPE	Control Event CoC	Control No CoC	RR	95%CI
RCT						
Atrey, 2018	0	29	0	29		
Beaupre, 2016	0	44	1	48	0.10	[0.00; 63.40]
Kim, 2013	0	100	0	100		
Cai, 2012	0	62	0	51		
Amanatullah, 2011	0	161	0	196		
Hamilton, 2010	0	87	2	177	0.10	[0.00; 54.77]
Lewis, 2010	0	26	0	30		
Pitto, 2008	0	20	0	20		
Ochs, 2007	0	31	0	35		
Sonny Bal, 2005	2	250	6	250	0.33	[0.07; 1.64]
Pitto, 2003	0	27	0	23		
Pitto, 2001	0	25	0	25		
Pooled RR		**862**		**984**	**0.29**	**[0.06; 1.31]**
Heterogeneity: $I^2 = 0\%, \chi^2_2 = 0.25$ ($p = 0.88$)						
Non-Randomized Comparative						
Van Loon, 2021	0	27	0	34		
Feng, 2019	1	77	0	93	13.28	[0.02; 8542.09]
Schmidt, 2003	0	30	0	30		
Pooled RR		**134**		**157**	**13.28**	**[0.02; 8542.09]**
Heterogeneity: not applicable						



Note: not estimable RR due to no events in both subgroups are left empty